



Tritium and its Safety Issues

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Changing the World's Energy Future

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7th IAEA DEMO Programme Workshop



Tritium Properties

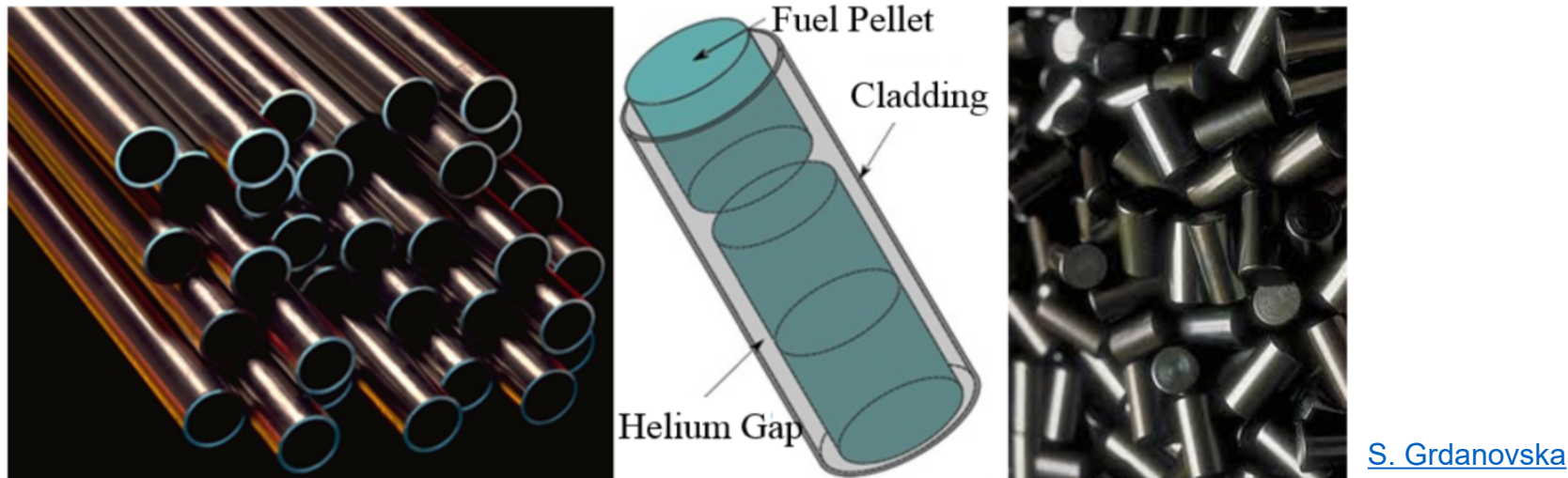
- Tritium is an isotope of hydrogen containing two neutrons; it is 50% of the fuel in a D-T fusion reactor
- Tritium has a 12.3 year half-life and undergoes a weak β decay (18.6 keV max)
- As an isotope of hydrogen, it is readily incorporated into water, organic molecules, and other materials
- The low decay energy poses no external radiation exposure hazard; absorption and especially inhalation are the primary exposure pathways
- In gaseous form (e.g. T_2 or HT), most inhaled tritium is simply exhaled with minimal absorption
- In oxidized (water) form (e.g. T_2O or HTO), it is readily absorbed and consequently 10,000x more hazardous; its biological half-life is ~10 days

Quantities of Tritium in Fusion Devices

- Fusion reactors consume tritium at rate of 55.8 kg/GW-y, and must breed it the same rate or higher
- This is about 10^3 x the rate of production in a MSR, 10^6 x of a LWR
- The plasma burns only a small fraction each pass, so fueling rate must be 20-200x larger
- Future reactors will produce tritium in a breeding blanket at the same rate it is consumed or higher to fuel other devices
- Concerns include:
 - Permeation of tritium through high temperature structures (pipes, vessel walls, etc.)
 - Large tritium inventories in components (e.g. cryopumps), tritium plant (~multiple kg)

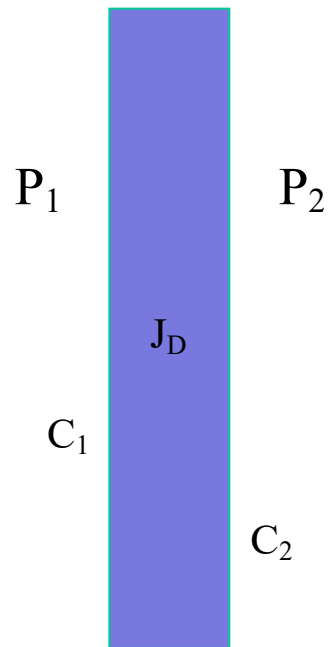
Confinement

- The primary radionuclide confinement barrier in many systems is simple: a sealed can (e.g., fission reactor fuel cladding)
 - Releases occur in the event of failures/leaks

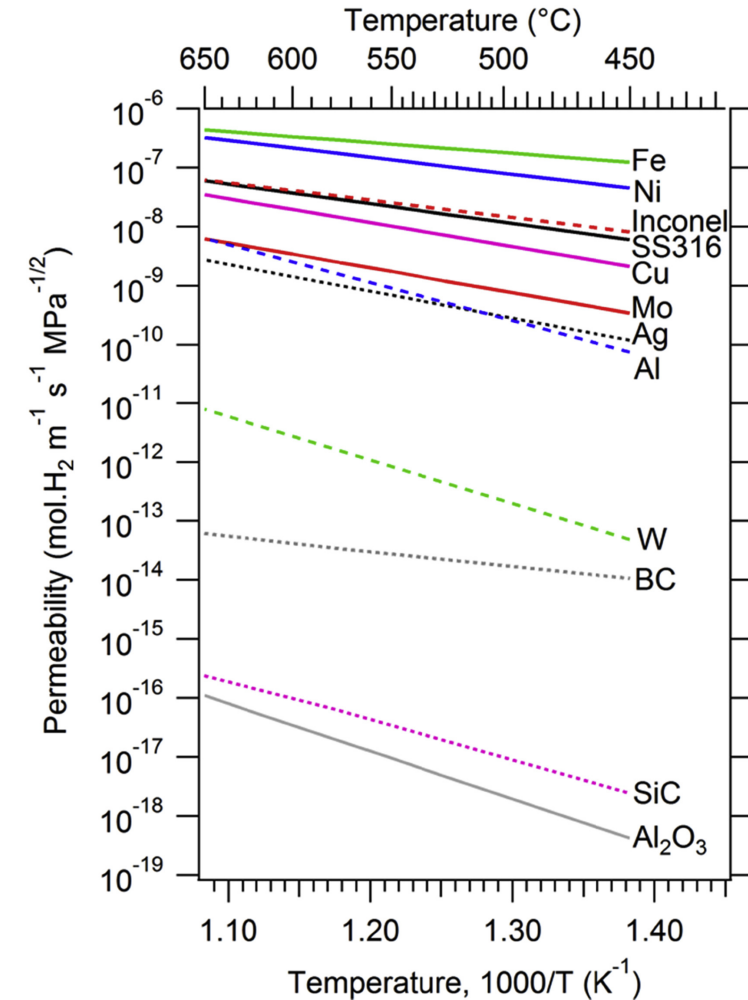


- This strategy is never perfect for tritium, which can permeate directly through solid metals and other materials

Tritium Permeation



- Tritium diffuses through solids: [REDACTED]
- At gas-solid interfaces, we usually assume the partial pressure in the gas and concentration at the solid are related by Sieverts' Law: [REDACTED]
- The square root dependence of permeation flux on partial pressure is well verified at high pressures
- The diffusivity and solubility (and their product permeability) are material properties that follow an Arrhenius law with temperature



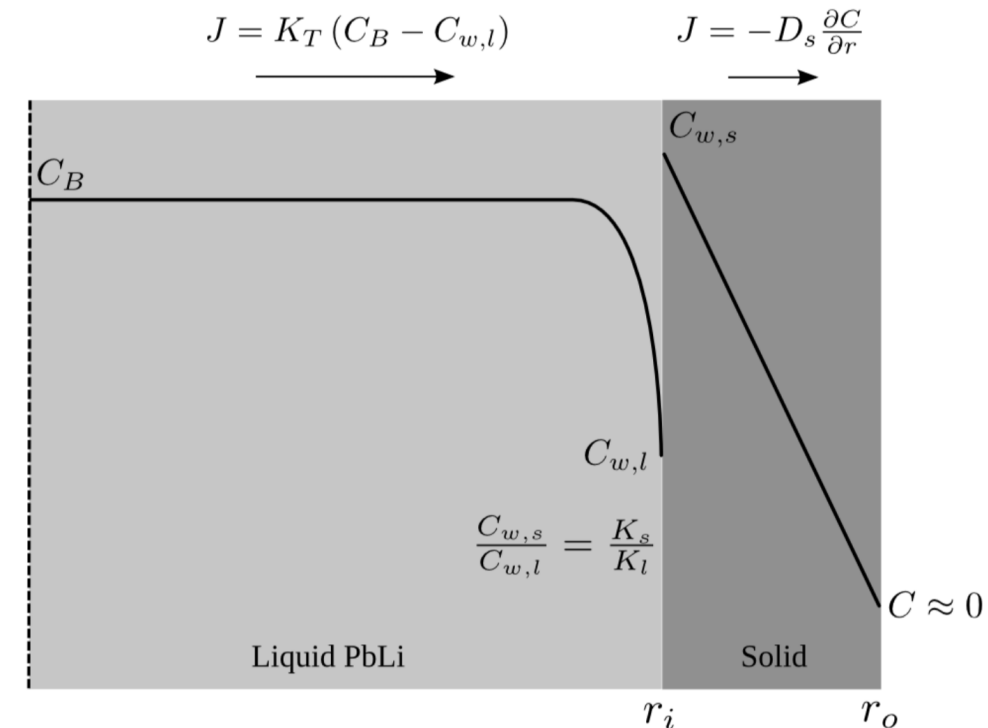
[D. Sheppard, J. All. Com. 787 \(2019\) 1225-1237.](#)

Other relevant transport phenomena

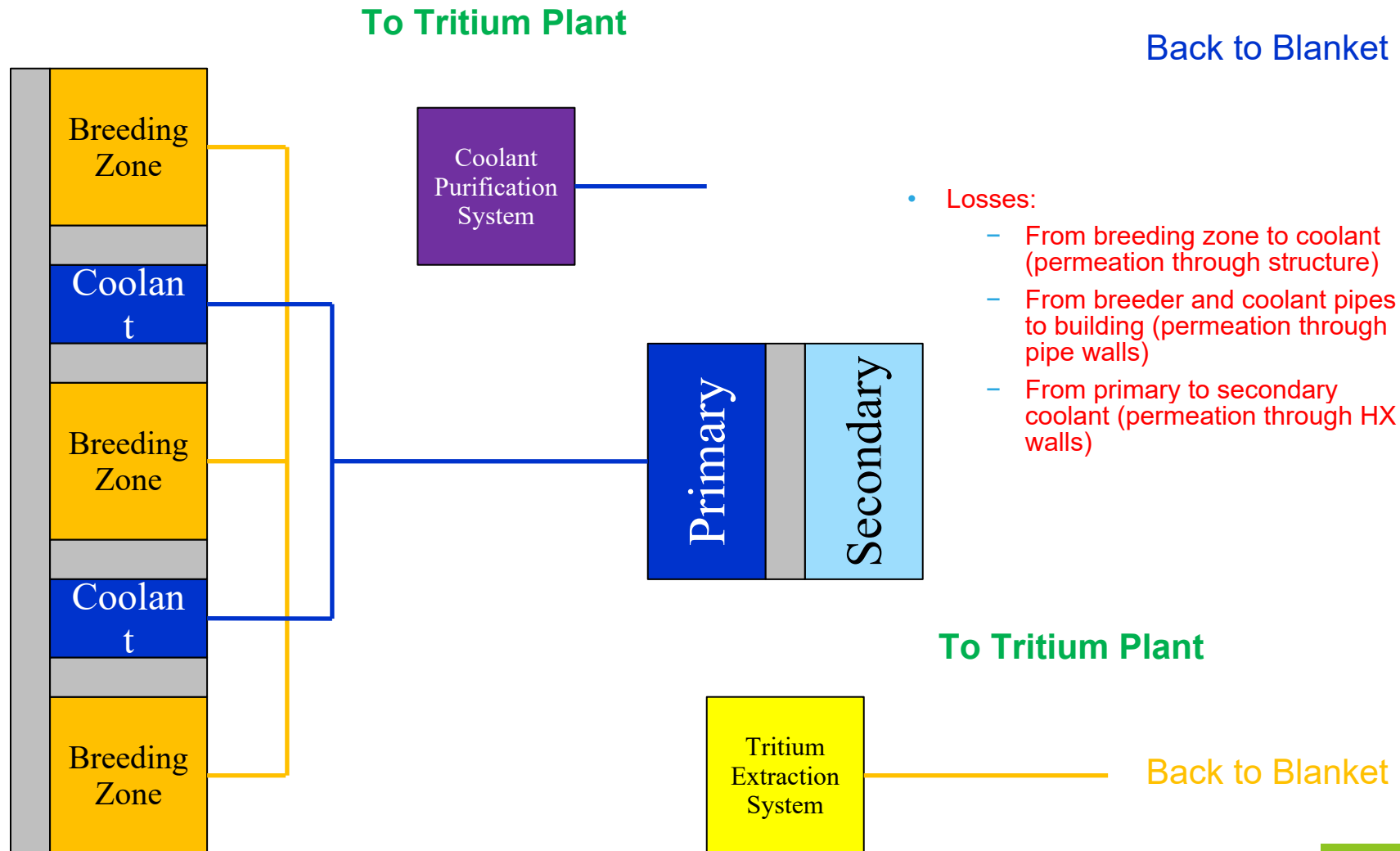
- Diffusion through metals may not always be the rate-limiting effect in tritium permeation through systems
- Other potentially important phenomena include:
 - Surface/interface reactions
 - E.g. competing dissociation and recombination reactions at gas/solid interfaces:
 - “Mass transfer” in fluids
 - Analagous to convective heat transfer
 - Mass transfer coefficients may be obtained from CFD or CMHD analyses, or from correlations if known:

$$Sh = \frac{K_L r_i}{D}$$

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Tritium flows and loss paths

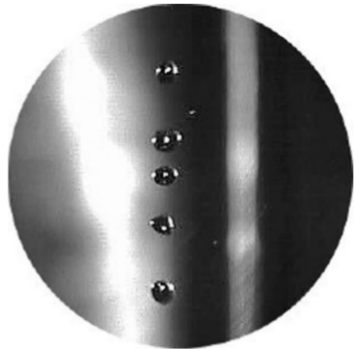


- Losses:
 - From breeding zone to coolant (permeation through structure)
 - From breeder and coolant pipes to building (permeation through pipe walls)
 - From primary to secondary coolant (permeation through HX walls)

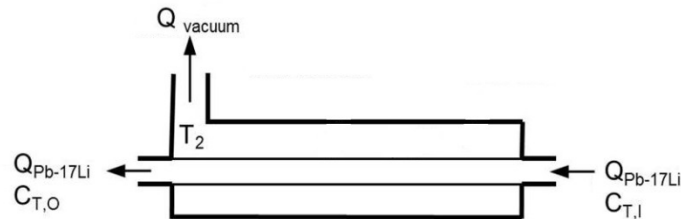
Safety analyses seek to quantify the rate of tritium loss through all systems, in both normal and off-normal operating scenarios

Mitigations

- Any improvements in tritium processing system efficiencies will help reduce inventories and tritium permeation losses, e.g.:
- Direct Internal Recycling (DIR) of direct unburnt D/T (with separation of He, Ne, N, etc.)
- Efficient tritium extraction from breeder and coolants



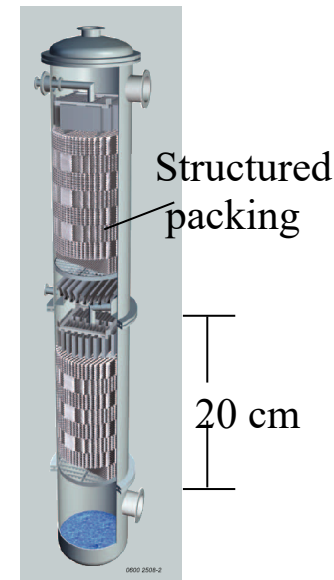
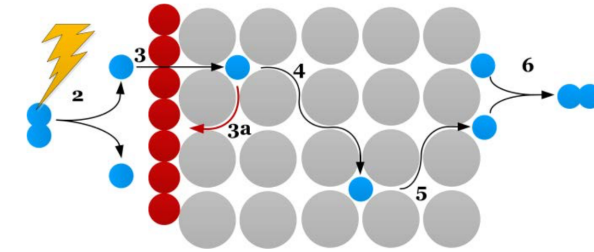
²F. Okino, *FED* **87** (2012) 1014-1018



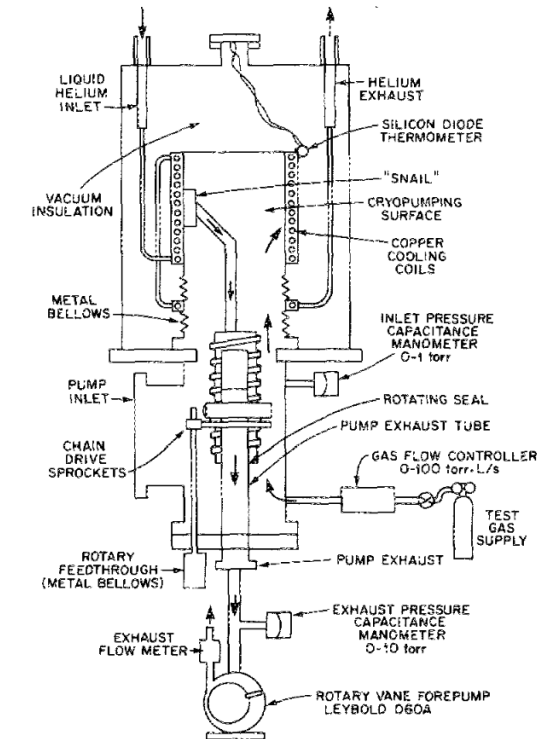
²O. Gastaldi et al. *FED* **83** (2008) 1340–1347



B. Peters, KIT



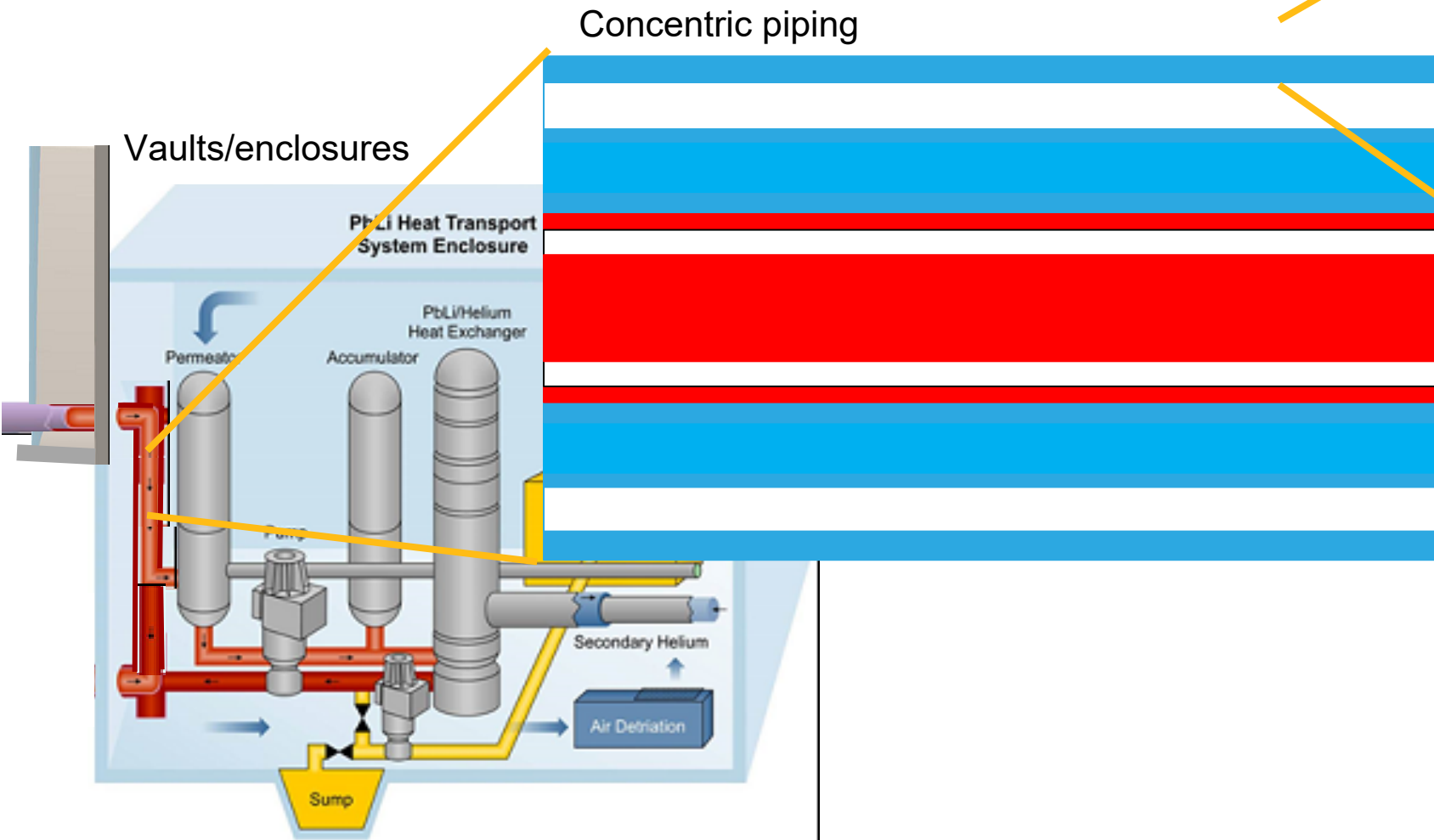
Sulzer Column



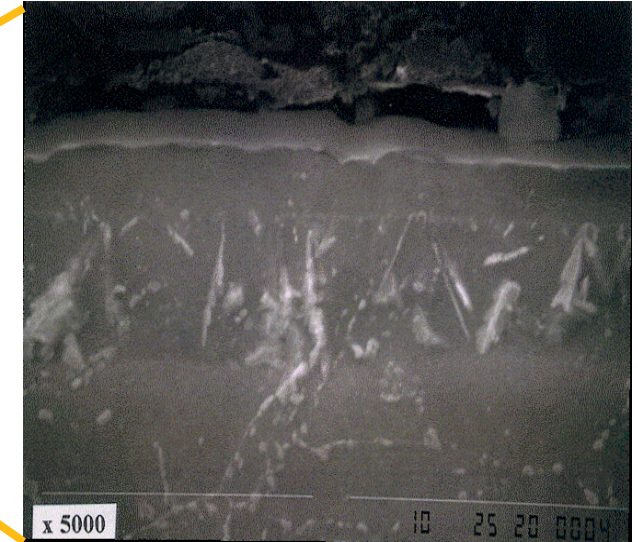
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Barriers

- Barriers at multiple scales may be employed to inhibit permeation

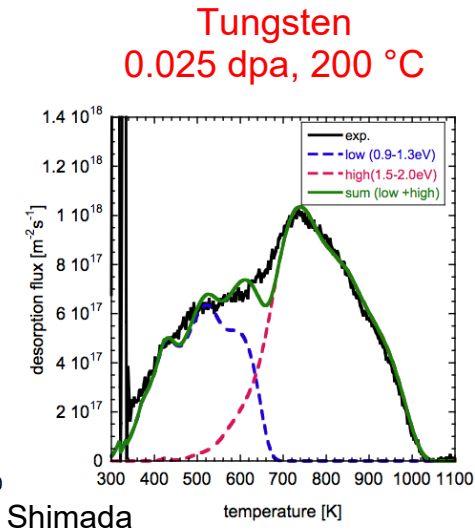
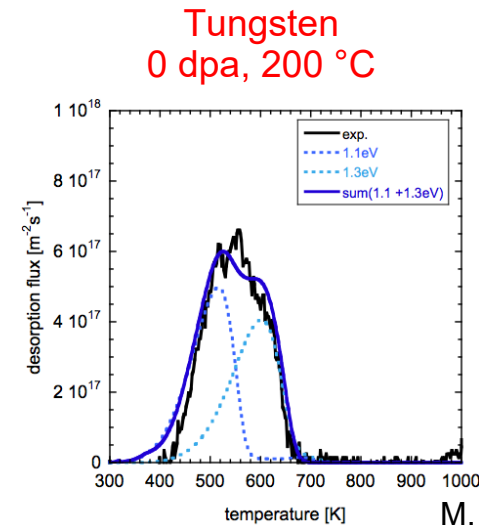


Permeation barrier coatings

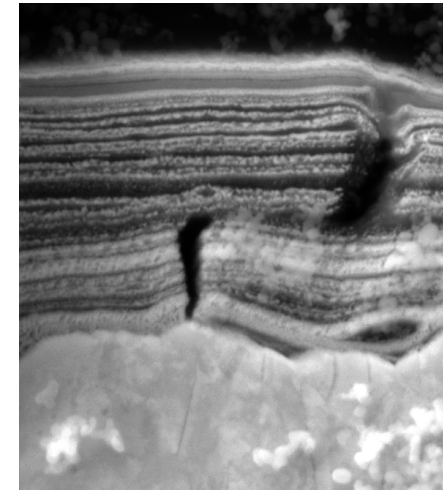


Tritium inventory in in-vessel components

- Neutron irradiation damage (and ion irradiation damage to plasma facing components) create additional trap sites for tritium that can increase inventory stored in components
- This inventory could be released in a temperature excursion
- A better quantitative understanding of trapping is needed, to understand quantitative effects of:
 - Fluence (both ion and neutron)
 - Structural changes, where they occur and how they modify bulk tritium transport properties
 - Morphological changes like co-deposited layers



M. Shimada



[DC. McDonald, JET](#)

Standards and Regulations

- Radioactive and hazardous material confinement barriers of sufficient number, strength, leak tightness, and reliability shall be incorporated in the design of fusion facilities to prevent releases of radioactive and/or hazardous materials from exceeding evaluation guidelines during normal operation or during off-normal conditions:

TABLE 1. Requirements for protection of the public from exposure to radiation^a

	Fusion radiological release requirement	Regulatory limit (evaluation guideline)
Normal and anticipated operational occurrences	0.1 mSv/yr (10 mrem/yr)	1 mSv/yr (100 mrem/yr)
Off-normal conditions (per event)	10 mSv (1 rem) (No public evacuation)	250 mSv (25 rem)

- DOE standard limits on routine airborne and liquid releases:
 - National Emission Standards for Hazardous Air Pollutants (40 CFR 61): 10 mrem/yr
 - National Primary Drinking Water Regulations (40 CFR 141.16): 4 mrem/yr
 - All sources (10 CFR 20.1301): 100 mrem/yr

¹DOE-STD-6002-96, "Safety of Magnetic Fusion Facilities: Requirements" (under revision)

²DOE-STD-6003-96, "Safety of Magnetic Fusion Facilities: Guidance" (under revision)